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Nidhaleddine Ben Cheikh and Christophe Rault

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Send correspondence to:
Christophe Rault
University of Orléans
chrault@hotmail.com

[*] ESSCA School of Management, France. E-mail address: nidhaleddine.bencheikh@essca.fr
[†] LEO, University of Orléans, Rue de Blois-BP 26739, 45067 Orléans, France, CESifo, and IZA (Germany), E-mail address: chrault@hotmail.com . Websites: http://chrault3.free.fr/

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Abstract

Although financial inclusion would induce greater pollutant emissions through economic activity, improved access to financial services may facilitate investment in clean technologies. This study investigates whether financial inclusion has influenced the dynamics of carbon dioxide (CO_2) emissions over the last decade using a sample of 70 countries. We implement panel threshold techniques to explore possible regime shifts in environmental quality. Our results reveal that the influence of increased financial access on air pollution depends on the economic development stage. While financial inclusion can increase CO_2 emissions in lower-income regimes, environmental quality appears to be enhanced, with more inclusiveness at later developmental stages. Less-developed countries require more robust environmental policies to align their financial inclusion initiatives with sustainable economic development.

Keywords: Financial inclusion, carbon emissions, panel threshold modeling
JEL Classifications: C23, O16, O44, Q53, Q56

ملخص

رغم أن الشمول المالي سيؤدي إلى زيادة انبعاثات الملوثات من خلال النشاط الاقتصادي، فإن تحسين فرص الحصول على الخدمات المالية قد ييسر الاستثمار في التكنولوجيات النظيفة. تبحث هذه الدراسة فيما إذا كان الشمول المالي قد أثر على ديناميكيات انبعاثات ثاني أكسيد الكربون على مدى العقد الماضي باستخدام عينة من 70 دولة. نحن نطبق تقنيات عتبة المسوح لاستكشاف التحولات المحتملة في النظام في الجودة البيئية. تكشف نتائجنا أن تأثير زيادة الوصول المالي على تلوث الهواء يعتمد على مرحلة التنمية الاقتصادية. وفي حين أن الشمول المالي يمكن أن يزيد من انبعاثات ثاني أكسيد الكربون في النظم ذات الدخل المنخفض، يبدو أن نوعية البيئة قد تحسنت، مع زيادة الشمولية في المراحل الإنمائية اللاحقة. وتحتاج البلدان الأقل نموا إلى سياسات بيئية أقوى لمواءمة مبادراتها المتعلقة بالإدماج المالي مع التنمية الاقتصادية المستدامة.

1. Introduction

Access to affordable financial products and services, as a cornerstone of the 2030 Sustainable Development Goals (SDGs), has grown significantly over the past decade.[2] According to the World Bank's latest Global Findex data, worldwide account ownership reached 76% in 2021, up from 51% in 2011 (Demirgüç-Kunt, et al., 2022). In recent years, an increasing number of studies have addressed the role of financial inclusion in economic development and growth processes (e.g., Daud et al., 2024; Emara et al., 2021; Ozturk and Ullah, 2022; Siddiki and Bala-Keffi, 2024). Nevertheless, in a comprehensive review, Demirgüç-Kunt et al. (2017) posited that the link between access to financing and economic growth remains controversial and that a relatively small amount of research has been conducted on the subject. It is agreed that better financial access would positively affect economic growth; however, the dynamics may be changing owing to the existence of a turning point. Using a sample of 44 sub-Saharan African (SSA) countries, Amponsah et al. (2021) found an inverted U-shaped pattern, suggesting that increased financial inclusion improves growth inclusiveness up to a threshold, after which it declines. Abdul Karim et al. (2022) investigated the presence of a threshold effect in the nexus between financial inclusion and economic growth. For a panel of 60 emerging and less-developed countries, the authors identified a certain threshold level beyond which the impact of increased financial access on growth declines. In addition, using firm-level data, Nizam et al. (2021) point out that the impact of financial affordability on business growth is significantly negative beyond a certain threshold.[3]

As increased access to affordable financial products/services stimulates consumption and economic activity, this raises the question of its possible effects on environmental quality. Using a sample of 31 Asian countries, Le et al. (2020) found that GHG emissions increased with improved access to banking facilities. Similarly, Zaidi et al. (2021) documented positive connections between access to financing, energy consumption, and carbon dioxide (CO_2) emissions in panel data from 23 OECD countries. Moreover, further financial accessibility may spur individuals and companies to seek green investments and environmentally friendly technologies. Therefore, the assumption of a linear or monotonic relationship between widening financial access and pollutant emissions may be misleading. Shahbaz et al. (2022) found that the impact of access to financing on air pollution is asymmetric and varies according to geographical location. Financial inclusion also has a significant effect in regions with low GHG emissions; however, this effect is not statistically significant in areas with higher levels of emissions. Renzhi and Baek (2020) tested for the presence of an environmental Kuznets curve (EKC) between financial inclusion and CO_2 emissions in a large panel of 103 countries. The authors found that greater access to financing increases pollutant emissions in the early stages, but can be helpful for environmental preservation at a later stage. From an econometric perspective, Renzhi and Baek (2020) introduced a quadratic term for financial inclusion in their empirical specification to identify the presence of an inverted U-shaped curve. The estimated coefficient of financial inclusion is positive, whereas the coefficient of its quadratic term is negative, indicating the presence of a turning point.

This study aims to investigate the dynamic relationship between financial inclusion and greenhouse gas (GHG) emissions. We propose a new approach to explore the impact of financial inclusion on CO_2 emissions without imposing any prior shape on their relationship. We use a panel threshold regression model in which the possible existence of a turning point is

[2] Financial inclusion has a prominent position in that it is featured in 8 of the UN's 17 SDGs.
[3] More broadly, the presence of a threshold effect in growth–financial development nexus has been documented in previous literature (e.g., Arcand et al., 2015; Law & Singh, 2014; Beck et al., 2016).

properly captured from the data (e.g., Hansen, 1999; Kremer, et al., 2013; Seo and Shin, 2016). We investigate the presence of the threshold effect by considering the moderating role of income level, institutional quality, and information and communication technology (ICT) infrastructure. We also propose using principal component analysis (PCA) to compute a composite index of financial inclusion from various indicators related to the affordability of financial products. Given the myriad of proxies for financial inclusion, the advantage of using PCA is that it reduces data dimensionality while retaining the most significant information. Our study covers a sample of 70 countries during the 2010–2019 period for which data on financial access are available.

The remainder of the paper is organized as follows. Section 2 reviews the related literature on financial inclusion and the possible presence of a threshold effect. Section 3 describes the empirical approach and data. The main empirical results are presented in Section 4. Finally, in Section 5, we present our concluding remarks.

2. Literature review

Despite the extensive literature linking economic activity and financial development, the existence of nonlinearity remains controversial and most of the empirical evidence is inconclusive. Several studies have confirmed that the effects of access to finance on economic growth are time-varying and depend on the stage and level of economic development (e.g., Deidda and Fattouh, 2002; Arcand et al., 2015; Huang and Lin, 2009; Law et al., 2013). Some empirical studies have highlighted the negative effects of higher financial development levels on economic growth. For a group of 50 emerging and developed countries, Cecchetti and Kharroubi (2012) documented an inverted U-shaped relationship between the size of a financial system and growth. Specifically, a larger financial system benefits real growth up to a certain threshold. However, a point arrives at which greater financial development can reduce growth. Similarly, Law and Singh (2014) applied a dynamic panel threshold framework to capture the possible existence of regime-switching behavior in a sample of 87 developed and developing countries and reported that above a certain threshold, the financial development level is ineffective and even detrimental to growth. However, below the estimated threshold, the spread of financial services is beneficial. Law and Singh (2014) emphasized that policymakers should seek the optimal level of financial affordability to promote economic development.

However, other studies have reported different patterns of the growth–finance nexus, with the "bright" side of financial development being more pronounced at later stages of economic development. For low-income economies, the relationship is not significant or is weak, whereas enhancing access to financial services would boost economic activity in high-income countries (e.g., Hung, 2009; Rioja and Valev, 2004). Similarly, based on a sample of 32 countries, Beck et al. (2016) reported that adopting financial innovations would help countries achieve higher income growth. Nevertheless, the authors admitted that innovative financial activities can be synonymous with higher profitability volatility, and thus, further bank fragility. Given the inconclusiveness of existing empirical studies, the use of an appropriate functional form and relevant econometric techniques is crucial to accurately estimate the connection between income growth and the extent of financial development. The assumption of linearity without testing for possible regime shifts can be misleading, explaining why a negative association can be found empirically between economic growth and financing when a linear form is considered.

As higher economic growth is associated with higher GHG emissions, exploring how improved access to financing affects environmental quality would provide interesting findings. The validity of the EKC assumption (i.e., that air pollution declines as income levels rise above a certain threshold) has long been debated (for a recent discussion, see e.g., Borowiec and Papież, 2024; Horky and Fidrmuc, 2024; Li, et al., 2024). Despite the myriad of studies on the growth-CO_2 nexus, research on the potential impact of financial inclusion on environmental performance remains scarce. Using the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) model of Chudik et al. (2016), Cai and Wei (2023) measured the effects of increased financial access on carbon emissions for a panel of 32 countries of the Belt and Road Initiative. Unlike the development of renewable energy, improving the affordability of financial services is ineffective in mitigating environmental pollution. Using both linear and nonlinear panel data specifications, Badeeb et al. (2023) investigated the key drivers of financial service affordability. Based on panel data from 14 OECD countries, they documented that clean energy use would promote financial inclusion, while greater exploitation of natural resources would hinder it. Badeeb et al. (2023) introduced a quadratic term to examine the nonlinear relationship between natural resource extraction and financial inclusion. The authors suggested that the negative effects of access to financing are significantly greater when the degree of dependence on natural resources is below a certain threshold.

In line with the EKC literature, recent empirical studies have tested whether a turning point or threshold effect exists in the dynamics of financial inclusion. Using a large sample of 84 countries, Daud and Ahmad (2023) analyzed the relationship between economic growth, financial access, and digital technology, and based on a dynamic panel data model, the authors reported that a threshold level of financial inclusion must be reached before it has a positive impact on a country's growth. Daud and Ahmad (2023) also recognized that improving digital technology infrastructure plays a key role in accelerating financial inclusion.[4] In addition, some studies have investigated the moderating effect of the nexus between air pollutants and financial inclusion. Using Machado and Silva's (2019) moments quantile regression method with data from 27 European countries, Fareed et al. (2022) highlighted the importance of innovation activity in moderating the positive association between financial access and carbon emissions, appearing as an effective mitigation measure. Notably, an interaction term (i.e., a multiplication of the innovation activity and financial inclusion variables) was introduced in their empirical specifications to capture the possible presence of a mediating effect. To avoid the use of an arbitrary specification for a moderating effect, we propose the use of nonlinear panel data modeling, in which the presence of regime-switching behavior in financial inclusion can be captured properly from the data. The implementation of panel threshold regression models has had notable success in the energy economics literature. Ben Cheikh and Ben Zaied (2023) applied a dynamic panel threshold regression model that allows capturing the impact of geopolitical conflicts on the energy transition. Their results highlight the key role of economic development in the transition to low-carbon energy sources.

3. Empirical specification and data

The panel threshold regression model allows us to identify any regime shifts in the relationship between inclusiveness and emissions. The model can be written as a single-threshold model (two regimes), as follows:

[4] The overall level of financial access remained stable and strong throughout the COVID-19 outbreak, which was mainly due to the greater use of digital financial services that played a key role in supporting access to banking facilities during the health crisis (Financial Access Survey, FAS, 2023).

$$\Delta e_{it} = (1, x'_{it})\beta_1 \mathbb{I}\{q_{it} \leq \gamma\} + (1, x'_{it})\beta_2 \mathbb{I}\{q_{it} > \gamma\} + \varepsilon_{it}, \quad (1)$$

where Δe_{it} is the dependent variable represented by the change in CO_2 emissions (measured in metric tons per capita).[5] $\mathbb{I}\{\cdot\}$ is an indicator function represented by the threshold variable q_{it}, and the threshold parameter γ. The latter allows the equation to be divided into two different regimes with coefficients β_1 and β_2. x_{it} is a vector of country-specific and time-varying explanatory variables that may influence environment quality, including the composite index of financial inclusion. x_{it} may have different effects on pollutant emissions depending on whether the threshold variable q_{it} is above or below a certain value of γ, with $\beta_1 \neq \beta_2$.[6] ε_{it} represents the error components defined as $\varepsilon_{it} = \mu_i + \nu_{it}$, where μ_i is the country-specific fixed effect and ν_{it} is a zero mean idiosyncratic error.

Table 1. Descriptive statistics

	Mean	SD	Min.	Q_1 (.25)	Median	Q_2 (.75)	Max.
CO_2 emissions	4.35	4.91	0.06	1.29	3.55	5.76	34.19
GDP per capita	13837.70	17647.30	479.88	2613.53	6147.29	15610.20	88413.19
Energy intensity	4.41	2.25	1.32	3.01	3.68	5.05	14.75
Trade openness (% of GDP)	90.74	55.12	22.49	55.12	79.84	107.83	379.10
FDI (% of GDP)	4.95	9.79	-40.08	1.31	2.69	4.98	102.31
Financial inclusion indicators							
ATMs	55.33	47.31	1.43	20.27	50.93	72.38	288.59
Bank branches	19.77	15.71	0.42	8.95	14.85	24.85	95.93
Bank accounts	1511.23	1277.35	71.67	635.68	1139.14	2079.99	7270.62
Deposits (% of GDP)	58.83	40.59	11.13	33.96	45.82	71.79	251.26
Loans (% of GDP)	54.77	34.31	5.95	28.91	47.97	74.72	167.85
PCA-based financial index	0.00	1.68	-2.58	-1.37	-0.21	0.96	4.67
ICT infrastructure							
Fixed telephone subscriptions	19.06	15.84	0.09	5.63	15.64	30.05	62.85
Mobile cellular subscriptions	112.35	30.61	30.70	93.97	113.20	132.09	212.64
Individuals using the Internet	50.38	27.07	3.00	25.65	52.95	73.13	99.65
PCA-based ICT index	0.00	1.48	-3.14	-1.12	0.07	1.25	2.94
Governance Indicators							
Government Effectiveness	0.23	0.81	-1.39	-0.43	0.12	0.87	2.24
Control of Corruption	0.07	0.91	-1.39	-0.60	-0.23	0.71	2.28
Political Stability	-0.03	0.85	-2.81	-0.59	0.01	0.67	1.62
Regulatory Quality	0.27	0.82	-1.73	-0.33	0.22	0.85	2.26
Rule of Law	0.12	0.85	-1.45	-0.56	-0.10	0.75	2.02
Voice and Accountability	0.15	0.80	-2.12	-0.42	0.11	0.79	1.69
PCA-based governance index	0.00	2.22	-4.19	-1.69	-0.47	1.70	4.98

[5] The existing literature has also considered other indicators such as the level of CO_2 intensity (for a discussion, see Ben Cheikh and Ben Zaied, 2024a).

[6] As discussed by Seo and Shin (2016), x_{it} may include the lagged dependent variable. Furthermore, the threshold variable q_{it} could be an element of the explanatory variables or a variable external to the model.

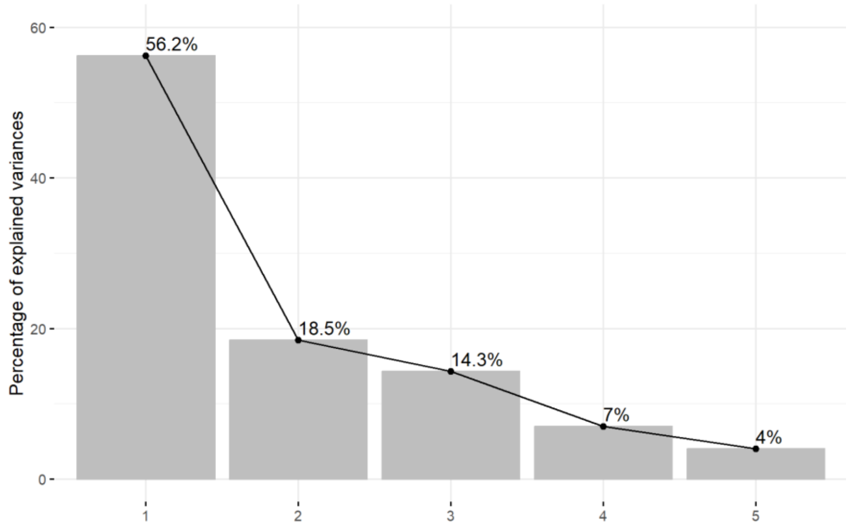
In our applications, different threshold variables q_{it} are considered that may influence the nexus between access to financing and air pollutants, such as income level gdp_{it}, governance quality GOV_{it}, and ICT infrastructure ICT_{it}: $q_{it} = (gdp_{it}; ICT_{it}; GOV_{it})$.[7] First, the moderating role of income level is considered to test for the existence of an inverted U-shaped curve in line with the EKC assumption (e.g., Renzhi and Baek, 2020). Second, previous studies have established the importance of governance quality in promoting financial development. For example, based on dynamic panel data modeling, Zeqiraj et al. (2022) identified the role of institutional quality in improving access to financial services in a sample of 73 developing countries. Their point estimates suggest that a 1% increase in governance quality increases access to finance by 0.64%. Moreover, using a sample of 85 countries, Law et al. (2013) documented that once a certain threshold of institutional quality is reached, financial development has a positive impact on economic growth. Finally, we consider ICT penetration as a threshold variable because of its possible effects on environmental performance e.g., Asongu et al., 2018; Ben Lahouel et al., 2021; Usman et al., 2021), as well as its complementarity with financial inclusion (e.g., Chatterjee, 2020). In our nonlinear panel data model, the above-threshold variables are allowed to interact directly with the composite index of financial inclusion.

As a key explanatory variable, we compute a composite financial inclusion index using PCA from different indicators, which is common in this type of literature (e.g., Ahamed and Mallick, 2019; Badeeb et al., 2023; Kebede et al., 2021).[8] We consider five measures of financial inclusion: ATMs per 100,000 adults, bank branches per 100,000 adults, bank accounts per 1,000 adults, outstanding deposits from commercial banks (% of GDP), and outstanding loans from commercial banks (% of GDP) (e.g., Pradhan et al., 2021; Zeqiraj et al., 2022). The five indicators of financial inclusion are normalized using z-score transformation, which is the most common standardization approach. The PCA results are shown in Figure 1. The scree plot shows that the first principal component explains a large proportion of the variability in the financial inclusion data, accounting for more than 56.2% of the total variance. For the ICT and governance-quality variables, the first component retains 72.8% and 82.3% of the information, respectively. The eigenvalues for each principal component are listed in Table A2 of the Appendix. Figure 2 illustrates the contribution of each variable to the first component. It appears that outstanding loans (% of GDP) and bank accounts (per 1,000 adults) correspond to the financial indicators with the highest contributions, whereas the number of bank branches (per 100,000 adults) is the lowest.

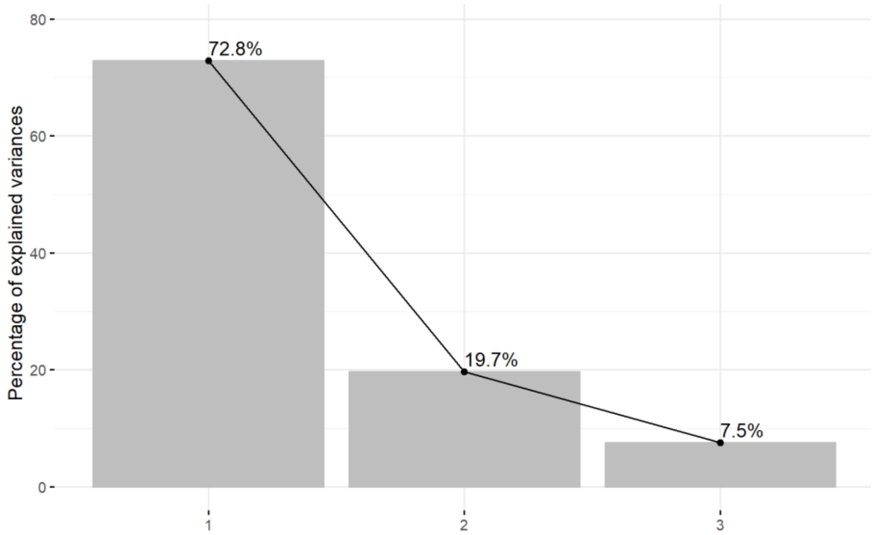
[7] It is possible to consider other threshold variables to test their moderating effect, such as urbanization, industrialization, or renewable use. Unfortunately, when we perform threshold effect tests, the null assumption of no threshold cannot be rejected for these types of variables.

[8] While the most two common approaches used in this context are PCA and common factor analysis (CFA), the existing literature showed a preference for PCA as it is not necessary to make additional assumptions about the original data, such as selecting the underlying common factors (see e.g., Ben Cheikh et al., 2023).

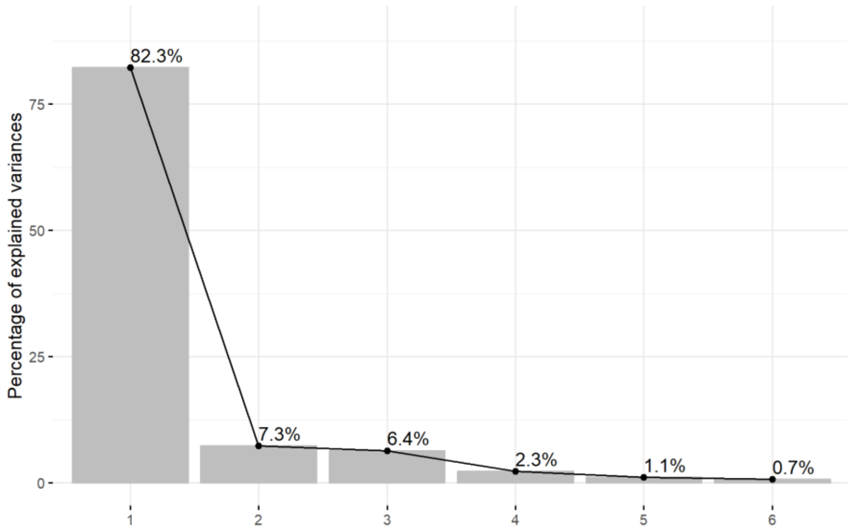
Figure 1. The scree plots from PCA



(a) Financial inclusion indicators

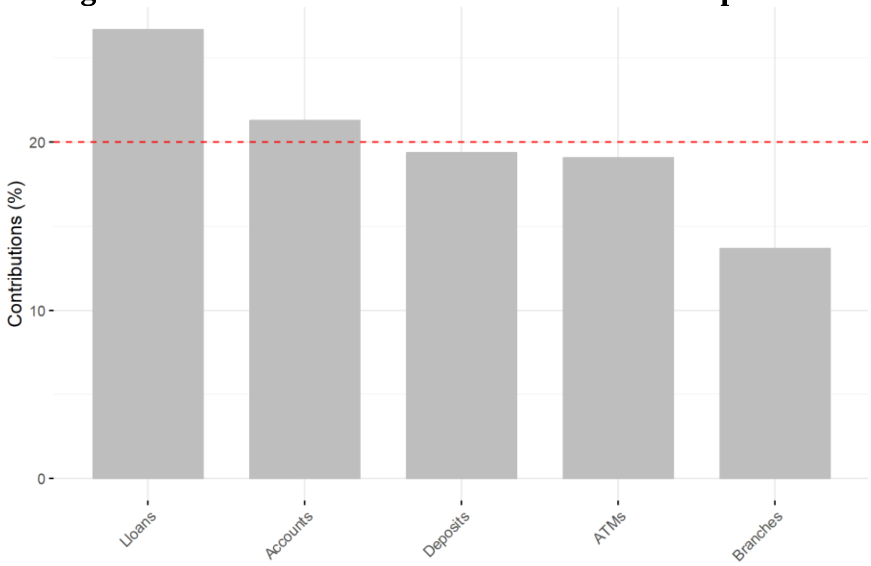


(b) ICT indicators

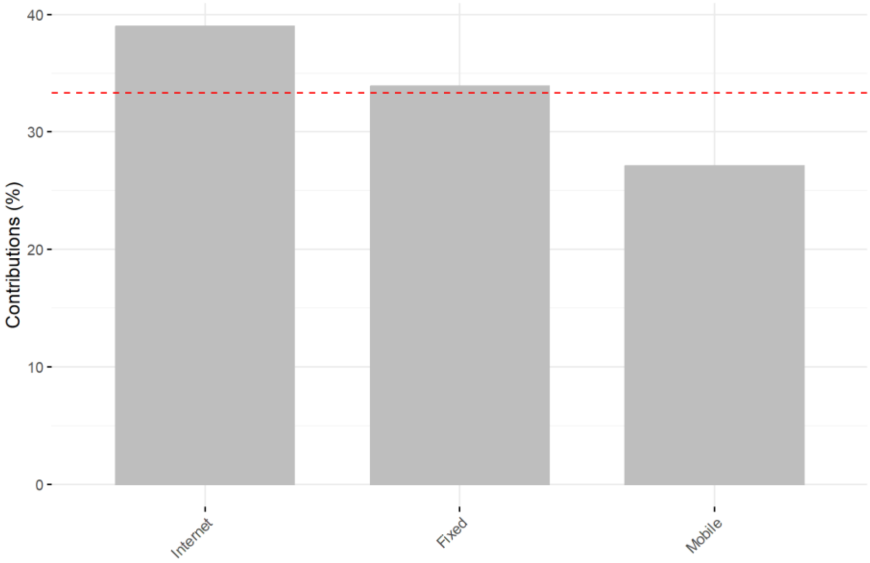


(c) Governance indicators

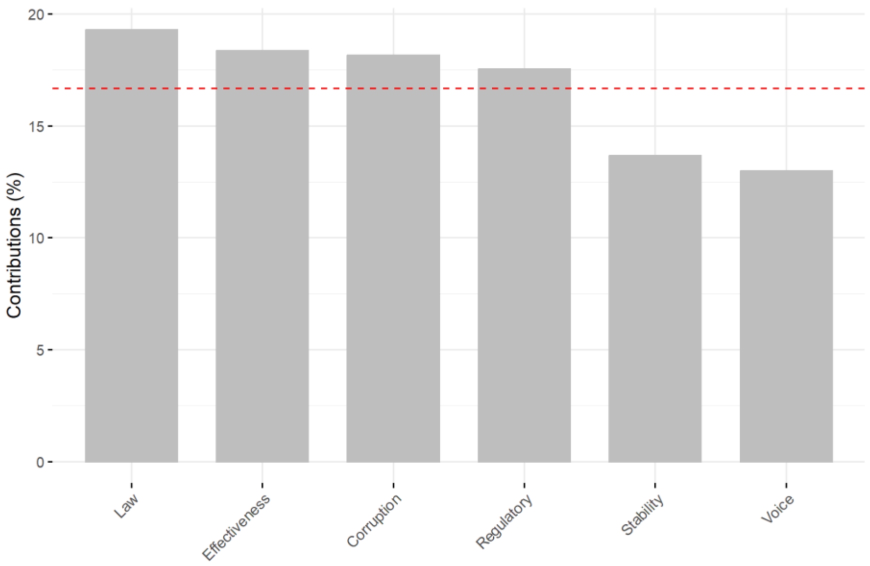
Figure 2. Variables contributions in the first component



(a) Financial inclusion variables



(b) ICT variables



(c) Governance variables

Additional explanatory variables have been introduced as potential drivers of air quality, including GDP per capita growth, energy intensity, trade openness, and net FDI inflows (e.g., Ben Cheikh et al., 2021; Ozturk and Ullah, 2022; Zaidi et al., 2021). In line with the extant literature, we consider the quality of governance along six dimensions: government effectiveness, rule of law, control of corruption, political stability, regulatory quality, voice, and accountability (see Kaufmann et al., 2010). Finally, for ICT investments, three measures are used: mobile cellular subscriptions (per 100 people), fixed telephone subscriptions (per 100 people), and individuals using the Internet (% of the population). Composite indices are constructed from governance and ICT indicators using PCA (Figure 1).[9] Owing to data availability, annual data have been collected for a panel of 70 countries spanning the 2010–2019 period to obtain a strongly balanced panel.[10] The Financial Access Survey of the International Monetary Fund (IMF) is used as the source of financial inclusion indicators. Governance indicators are collected from the World Governance Indicators database of the World Bank, while ICT and macroeconomic variables are sourced from the World Development Indicators database of the World Bank. Table 1 presents the descriptive statistics of the key variables. Full details of the definitions and sources of the data are provided in Table OA1 of the Online Appendix.[11]

4. Empirical results

Given the possible changing behavior in the emissions-inclusiveness nexus, we assess the presence of nonlinearity or regime shifts with respect to three key macro variables: per capita income, ICT penetration, and institutional quality. We perform threshold effect tests using Hansen's (1999) procedure to identify the number of thresholds in the panel structure. Table 2 displays F-statistics, F_1, F_2, and F_3, and their asymptotic bootstrap p-values to assess the null assumptions of no, one, and two thresholds, respectively. When we test for the presence of the threshold effect with respect to the (log) level of GDP per capita, $q_{it} = gdp_{it}$, the null hypothesis of no threshold effect is strongly rejected, according to the p-value of F_1. The test statistic for a double threshold, F_2, is also significant at the 1% level, with a bootstrap p-value of 0.008. Finally, F_3 indicates that the null hypothesis of two thresholds at most cannot be rejected. Notably, a double-threshold panel data model has been used to assess the relationship between carbon emissions and income growth. For a group of 12 countries in the Middle East and North Africa (MENA), Ben Cheikh and Ben Zaied (2021) showed that three regimes can be distinguished in the CO_2–growth nexus, depending on the carbon content of fuels. Given the threshold test results in Table 2, a panel threshold regression model with two thresholds is more appropriate to describe the effects of financial inclusion on carbon emissions with respect to income levels. We revise Eq.(1) for the double-threshold model (three regimes) as follows:

$$\Delta e_{it} = (1, x'_{it})\beta_1 \mathbb{I}\{gdp_{it} \leq \gamma_1\} + (1, x'_{it})\beta_2 \mathbb{I}\{\gamma_1 \leq gdp_{it} \leq \gamma_2\} + (1, x'_{it})\beta_3 \mathbb{I}\{gdp_{it} > \gamma_2\} + \varepsilon_{it}, \qquad (2)$$

[9] We have performed panel unit root tests using the Breitung and Das (2005) test, which is robust to cross-sectional dependence. The results confirm the stationarity of our key variables. Panel unit root tests are not reported here to conserve space, but are available on request.

[10] Our study does not cover the recent context of global crises, such as the COVID-19 outbreak and the Russia–Ukraine war, owing to limited data availability (e.g., Ben Cheikh and Ben Zaied, 2024b, Ben Cheikh et al., 2022, for a recent literature).

[11] The panel of 70 countries, listed according to the World Bank regional classification, is provided in Table A1 in Appendix.

Threshold tests for the ICT composite index, $q_{it} = ICT_{it}$, show evidence of a single threshold at the 5% significance level. However, the presence of the threshold effect appears weak for the governance index, $q_{it} = GOV_{it}$, as the bootstrap p-value of F_1 is 0.103. Table 3 lists the estimation results obtained using the selected threshold variables.[12] Our threshold panel models are estimated using the first-differenced generalized method of moments (FD-GMM) approach, as in Seo and Shin (2016). Endogeneity problems in our panel threshold model are crucial to avoid, as they can lead to biased estimates and misleading results. Potential endogeneity issues can stem from our key explanatory variables, such as real GDP per capita growth, financial inclusion, ICT, and governance. Previous empirical studies have argued that financial inclusion cannot be considered a purely exogenous variable (e.g., Ozturk and Ullah, 2022; Renzhia and Baek, 2020; Zeqiraj et al., 2022). Furthermore, introducing income level as a threshold variable in the panel data framework, as specified in Eq.(2), can be problematic and lead to biased threshold estimates. For example, difference and system GMM estimators have been proposed to address the reverse causality between ICT and economic growth (e.g., Andrianaivo and Kpodar, 2011; Lee, et al., 2009). Seo and Shin's (2016) procedure is very convenient, as it can deal with potential endogeneity bias in both regressors and threshold variables.[13]

Table 2. Tests for threshold effects

Threshold variables (q_{it})	(1)	(2)	(3)
	gdp_{it}	ICT_{it}	GOV_{it}
Single-threshold effect test (H_0: no threshold)			
F_1	35.83	14.02	10.29
p-value	0.002	0.046	0.103
(5%, 1% critical value)	(23.510, 34.779)	(13.458, 16.961)	(12.744, 19.089)
Double-threshold effect test (H_0: at most one threshold)			
F_2	29.35	8.91	7.77
p-value	0.008	0.266	0.3433
(5%, 1% critical value)	(21.360, 27.828)	(16.204, 21.949)	(16.774, 23.908)
Triple-threshold effect test (H_0: at most two thresholds)			
F_3	11.40		
p-value	0.5900	-	-
(5%, 1% critical value)	(26.924, 36.528)		

The estimated thresholds $(\hat{\gamma}_1; \hat{\gamma}_2) = (8.11; 9.61)$, when we consider the log-level of GDP per capita as a threshold variable, allow for the distinction of three regimes with respect to income level: a *low-income regime* when GDP per capita is lower than 3,340$ (8.11 in logarithms); a *high-income regime* when the income per capita exceeds 15,033$ (9.61 in logarithms); and an intermediate *middle-income regime* between 3,340$ and 15,033$. The point estimates indicate that financial affordability includes higher CO_2 emissions in middle-income regimes, whereas environmental damage appears insignificant in lower-income regimes. However, improved access to financing is beneficial for environmental quality when the GDP per capita exceeds the threshold of 15,033$. An increase in financial inclusion has a significant negative effect on air pollutant emissions in the high-income regime. The 95% confidence intervals confirm the presence of regime dependence in the link between financial access and

[12] Since our primary concern in this study is the presence of an EKC between financial inclusion and air pollution, we do not report the coefficients on the other variables in the intermediate and upper regimes for reasons of space.
[13] The maximum lag order of the explanatory variables as instruments is set to four to avoid the problem of weak instruments.

CO_2 emissions owing to economic development levels, which is in line with the EKC assumption (see Figure 3).

A large stream of empirical literature has reported that the extent of access to financing is significantly and positively associated with air pollutant emissions. Using a panel of 76 emerging and developing economies over the 2011–2021 period, Khan et al. (2023) suggested that increased financial access is harmful to the environment. Furthermore, some studies have shown that the effect of financial access on GHG emissions can differ even within a country. For a panel of 284 Chinese cities over the 2011–2017 period, Wang et al. (2023) used a spatial econometric model that revealed that financial access positively influences air pollution in local cities but negatively affects neighboring cities. Our results confirm the non-monotonic effect of financial affordability on environmental quality. Without imposing an a priori restriction on the inclusiveness–emissions nexus, the implementation of a nonlinear panel data framework allows us to account for the presence of the threshold effect. Notably, the threshold effect is also confirmed for income growth, as the impact on emissions is significantly negative in the upper regime, which is consistent with previous studies (e.g., Arouri et al., 2012; Bimonte and Stabile, 2017; Yang et al., 2015). Furthermore, using a panel smooth transition regression model, Ben Cheikh et al. (2021) suggested an inverted U-shaped relationship between CO_2 emissions and energy consumption in the MENA region. Air pollution increases until an income threshold of $12,755.56 is reached, after which carbon emissions begin to decrease.

When considering the ICT index as a threshold variable, the effects of financial access appear to differ between the lower and upper regimes. However, the 95% confidence intervals indicate that the point estimates are not statistically significantly different. Although ICT can provide opportunities for the greater affordability of financial products, unfortunately, we cannot assert that ICT can help alleviate the environmental impact of financial accessibility. The literature has examined how the combination of financial inclusion and ICT affects economic activity. Andrianaivo and Kpodar (2011) documented that improved access to financial services is an important channel through which ICT penetration contributes to income growth. Using a sample of 44 African countries, the authors explained that the positive impact of mobile penetration on growth is more pronounced in countries with better access to financial products. Similarly, Wang et al. (2023) selected the most advanced African economies in terms of ICT infrastructure to assess their degree of growth inclusiveness. Using a GMM estimator for linear dynamic panel data models, the authors introduced an interaction term to capture the combined effect of ICT penetration and financial inclusion. Their empirical findings indicated that the interaction between financial access and ICT would foster inclusive growth, with a 1% increase in the interaction term and an increase in inclusiveness of 0.10%. Our empirical results do not show ICT to have an important role in the nexus between carbon emissions and the degree of financial inclusion. In contrast to the abovementioned studies, which considered an interaction term, our study implements a panel threshold regression to properly account for the mediating effects of ICT development.

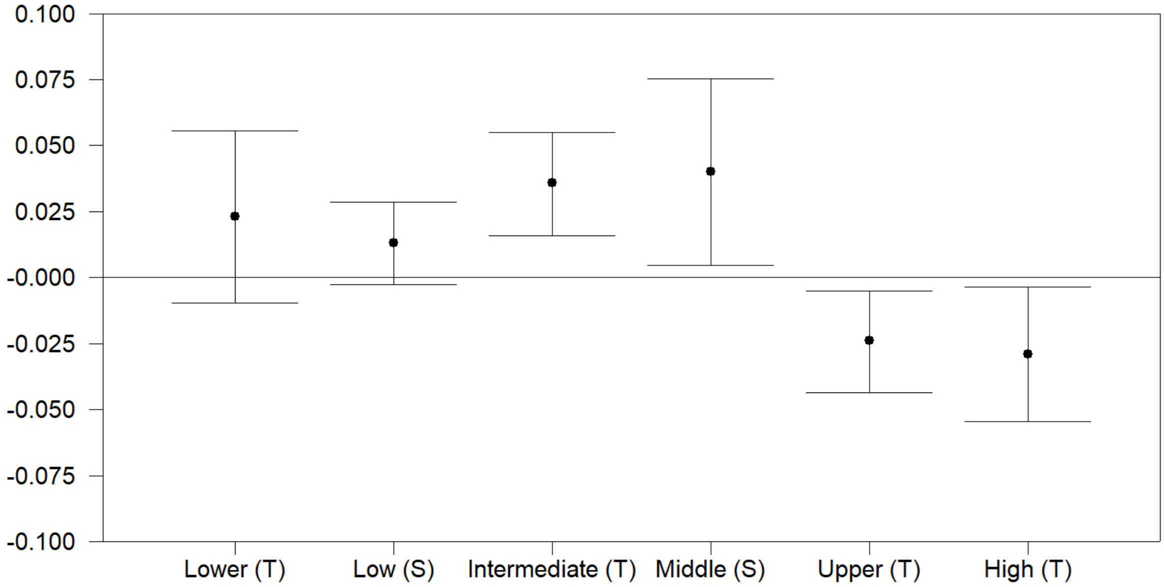
Table 3. Results from panel threshold models

	Dependent variable: Change in CO_2 emissions		
	(1)	(2)	(3)
Threshold variables (q_{it})	gdp_{it}	ICT_{it}	GOV_{it}
Threshold value ($\hat{\gamma}_1$)	8.114	0.344	0.1161
	{7.735; 8.491}	{0.236; 0.451}	{-0.217; 0.117}
Threshold value ($\hat{\gamma}_2$)	9.618	-	-
	{9.596; 9.620}		
Energy intensity	0.672***	0.5617***	0.671***
	(0.043)	(0.078)	(0.043)
Trade openness	-0.0003**	-0.0004**	-0.0004**
	(0.0001)	(0.0002)	(0.0002)
FDI inflows	0.0001	0.0000	0.0001
	(0.0002)	(0.0003)	(0.0002)
ICT	-0.039*	-0.0412***	-0.011*
	(0.0047)	(0.009)	(0.006)
Governance	-0.068	-0.034*	-0.086***
	(0.051)	(0.018)	(0.028)
Lower regime			
Income growth	1.303***	1.073***	1.174***
	(0.134)	(0.116)	(0.114)
	{1.038; 1.568}	{0.843; 1.302}	{0.949; 1.400}
Financial Inclusion	0.023	0.029*	0.016***
	(0.016)	(0.015)	(0.007)
	{-0.009; 0.055}	{-0.0007; 0.0591}	{0.002; 0.029}
Intermediate regime			
Income growth	0.944***		
	(0.164)	-	-
	{0.621; 1.266}		
Financial Inclusion	0.036***		
	(0.009)	-	-
	{0.016; 0.055}		
Upper regime			
Income growth	-0.818***	0.697*	-0.459
	(0.234)	(0.414)	(0.534)
	{-1.278; -0.359}	{-0.116; 1.511}	{-1.509; 0.590}
Financial Inclusion	-0.024***	-0.018**	-0.011
	(0.009)	(0.008)	(0.006)
	{-0.043; -0.005}	{-0.035; -0.0015}	{-0.024; .0021}
Observations	630	630	630
Adjusted R-squared	0.663	0.652	0.684
J-statistic	18.564	18.345	18.448
	[0.187]	[0.172]	[0.186]

Note: Standard errors are in parentheses. 95% confidence intervals are reported between braces. *J*-statistic corresponds to Hansen's (1982) test of over-identifying restrictions, with p-values in square brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Quality of governance as a moderating variable does not appear to lead to a significantly different impact of financial inclusion on pollution. Although improved access to financing appears to be detrimental to environmental performance when institutional quality is low, point estimates are not statistically different from those estimated when institutional quality is high. Previous studies suggest that institutional quality plays a key role in the affordability of financial services. Amponsah et al. (2021) highlighted the role of institutional quality in promoting growth inclusiveness in SSA countries, provided that an index of financial inclusion is included in the empirical specifications. Despite the lack of a mediating effect of governance quality, our results support the positive role of robust institutions in reducing environmental degradation. Classifying our sample of 70 countries according to the estimated GDP per capita thresholds, Table 5 shows that an increase in the quality of governance is associated with a decrease in CO_2 emissions, particularly for the high-income group (i.e., when GDP per capita is above \$15,033).

Figure 3. Impact of financial inclusion on emissions with 95% confidence intervals



Notes: The figure above shows the impact of financial inclusion on CO_2 emissions with 95% confidence intervals. Lower (T), Intermediate (T), and Upper (T) correspond to point estimates from the panel threshold regression model. Low (S), Middle (S), and High (S) correspond to point estimates from the split-sample approach.

Finally, we check the robustness of the moderating role of income level in the inclusiveness–emissions nexus using a split-sample approach. As a robustness check, Abdul Karim et al. (2022) proposed dividing their sample of 60 countries into the two categories of less-developed and emerging economies to ensure the positive effect of financial inclusion on economic growth. They found that the relationship varied across countries; for example, the effect on economic growth was more pronounced in countries with lower access to finance. In our empirical exercise, we proceed by splitting our panel of 70 countries into three groups with respect to the identified income threshold levels: $(\hat{\gamma}_1; \hat{\gamma}_2) = (8.11; 9.61)$. Then, the low-, middle-, and high-income groups are defined as consisting of countries with more than half of the observations of their GDP per capita being less than 3,340\$, between 3,340\$ and 15,033\$, and more than 15,033\$, respectively.[14]

[14] It is possible to classify countries with respect to the average of their annual GDP per capita over the 2010–2019 period. This does not change the outcome that financial inclusion has different effects on air quality depending on income levels.

Table 4. Sample split with respect to the estimated threshold level of GDP per capita

Countries in low-income regime		**Countries in middle-income regime**		**Countries in high-income regime**
$GDP_{it} \leq 3{,}340\$$		$3{,}340\$ < GDP_{it} \leq 15{,}033\$$		$GDP_{it} > 15{,}033\$$
Bangladesh	Togo	Algeria	Mauritius	Austria
Bhutan	Uganda	Argentina	Mexico	Belgium
Bolivia	Ukraine	Armenia	Mongolia	Estonia
Cameroon	Uzbekistan	Bosnia	Montenegro	Greece
Gambia	Zambia	Bulgaria	Namibia	Ireland
Ghana		Chile	North Macedonia	Italy
Honduras		Colombia	Panama	Japan
India		Costa Rica	Paraguay	Korea, Rep.
Indonesia		Croatia	Peru	Malta
Kenya		Ecuador	Poland	Netherlands
Morocco		Egypt, Arab Rep.	South Africa	Portugal
Mozambique		El Salvador	Thailand	Qatar
Nicaragua		Georgia	Türkiye	Singapore
Pakistan		Hungary	Uruguay	Spain
Philippines		Latvia		Sweden
Rwanda		Lebanon		Switzerland
Senegal		Malaysia		United Arab Emirates
Total: 22 countries		**Total: 31 countries**		**Total: 17 countries**

Note: Our panel of 70 countries is classified by income level based on the estimated per capita GDP threshold values.

Table 5. Estimation by group of countries with respect to income levels

	Dependent variable: Change in CO_2 emissions		
	(1)	(2)	(3)
	Low-income countries	Middle-income countries	High-income countries
	$GDP_{it} \leq 3{,}340\$$	$3{,}340\$ < GDP_{it} \leq 15{,}033\$$	$GDP_{it} > 15{,}033\$$
Income growth	1.135	0.890***	-0.756***
	(0.320)	(0.232)	(0.540)
Financial Inclusion	0.013*	0.040**	-0.029***
	(0.008)	(0.018)	(0.013)
Energy use	0.859***	0.727***	0.592***
	(0.157)	(0.051)	(0.074)
Trade openness	-0.0001	-0.0005**	-0.0017**
	(0.0004)	(0.000)	(0.0007)
FDI inflows	0.0014	-0.0005	0.0003
	(0.0023)	(0.0007)	(0.0004)
ICT	-0.012	-0.013*	-0.048**
	(0.021)	(0.007)	(0.023)
Governance	0.016	-0.046*	-0.023**
	(0.027)	(0.026)	(0.012)
Observations	198	279	153
Adjusted R-squared	0.627	0.668	0.680
J-statistic	16.676	17.065	17.978
	[0.148]	[0.175]	[0.181]

Note: Column (1) represents estimation results for the group of countries with $GDP_{it} \leq 3{,}340\$$; Column (2) for the group with $3{,}340\$ < GDP_{it} \leq 15{,}033\$$; and Column (3) for the group with $GDP_{it} > 15{,}033$. The standard errors are indicated in parentheses. *J*-statistic corresponds to Hansen's (1982) test of over-identifying restrictions, with *p*-values in square brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

The classifications of the countries with respect to their income levels are presented in Table 4. We then re-estimate the effects of financial inclusion separately for each identified cohort using the system GMM estimator of Blundell and Bond (1998).[15] Notably, for the high-income group, the threshold-based classification is slightly different from the World Bank regional classification. For example, Croatia, Hungary, and Latvia are listed as middle-income countries instead of high-income countries. Regarding the estimation results, Table 5 confirms that the threshold effect on income level remains robust. Contrary to low- and middle-income groups, widening financial coverage contributes to the mitigation of GHG emissions in high-income countries (see Figure 3).

In low-income countries, individuals are more concerned about improving their standard of living; therefore, any improvement in the affordability of financial services will lead to more consumption and greater pollutant emissions. However, beyond a certain income level, financial inclusion can help individuals shift toward more eco-friendly consumption habits. Less-developed countries need stronger environmental policies to align financial inclusion initiatives with sustainable economic development. Despite the current global financial flows supporting mitigation and adaptation actions, including public and private financial sources,

[15] The system GMM estimator performs better because the lagged level instruments in the Arellano and Bond (1991) procedure become weak with persistent series.

these are insufficient, especially in less developed countries (IPCC, 2023).[16] Environmental degradation can thus damage economic growth and reduce the availability of affordable financial products, further exacerbating the financial constraints on supporting climate action. Accelerated financial support in developing countries is critical for adopting low-carbon energy sources and addressing climate change.

5. Conclusion

In this study, we explore whether promoting financial inclusion affects CO_2 emissions in a sample of 70 countries over the 2010–2019 period. Panel threshold techniques are applied to account for possible regime shifts in the relationship between financial access and environmental quality. Threshold effect tests indicate that income levels have a significant moderating role, which is more apparent than other factors such as ICT and governance quality. Our results reveal that financial inclusion affects air pollution depending on economic development levels, which is consistent with the EKC. While financial inclusion increases CO_2 emissions in lower-income regimes, environmental quality appears to be enhanced, with more inclusiveness at later stages of development. In lower-income countries, individuals are more concerned with improving their standard of living; therefore, any improvement in the affordability of financial products and services will lead to more consumption and greater pollutant emissions. However, beyond a certain income level, financial inclusion can help individuals shift toward more eco-friendly consumption habits. In addition, with improvements in living standards, financial inclusion allows access to new investment opportunities, including environmentally responsible ones.

Less-developed countries need stronger environmental policies to align financial inclusion initiatives with sustainable economic development. However, despite increased awareness of climate risk, current financial support falls short of what is needed for climate adaptation and meeting mitigation targets. Energy transition lags in most developing countries, as public and private financial flows for fossil fuels are still higher than those for renewables. Greater international financial cooperation and coordinated multilateral actions are needed to accelerate the transition toward clean energy and reduce GHG emissions. Improving access to affordable financial services, especially in vulnerable developing regions, is critical for achieving sustainable and climate-resilient development. Finally, we note that data limitation was the main challenge in the present study, wherein the number of time-series observations, T, was small. If a longer timeframe is available, the possible existence of a cointegrating relationship can be used to assess the long-term effects of financial accessibility on environmental quality. GMM-type estimators (Arellano and Bond, 1991; Blundell and Bond, 1998) also assume that the coefficients are homogeneous across cross-sections N, given the short time dimension T of the panel. With large time-series data available for each cross-unit, heterogeneous slope coefficients can be estimated using panel time-series methods (see, e.g., Chudik and Pesaran, 2015). This is very useful for assessing the differences in the CO_2-inclusiveness nexus across our sample of countries.

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Appendix

Table A1. The sample of 70 countries based on the World Bank region classification

Geographic region	Country	Geographic region	Country	Geographic region	Country	Geographic region	Country
East Asia and Pacific	Indonesia	*High income (continued)*	Greece	*Latin America and the Caribbean*	Argentina	*South Asia*	Bangladesh
	Malaysia		Hungary		Bolivia		Bhutan
	Mongolia		Ireland		Chile		India
	Philippines		Italy		Colombia		Pakistan
	Thailand		Japan		Costa Rica	*Sub-Saharan Africa*	Cameroon
	Armenia		Korea, Rep.		El Salvador		Gambia
Europe and Central Asia	Bosnia		Latvia		Honduras		Ghana
	Bulgaria		Malta		Mexico		Kenya
	Georgia		Netherlands		Nicaragua		Mauritius
	Montenegro		Poland		Panama		Mozambique
	North Macedonia		Portugal		Paraguay		Namibia
	Türkiye		Qatar		Peru		Rwanda
	Ukraine		Saudi Arabia	*The Middle East and North Africa*	Algeria		Senegal
	Uzbekistan		Singapore		Egypt, Arab Rep.		South Africa
High income	Austria		Spain		Jordan		Togo
	Belgium		Sweden		Lebanon		Uganda
	Croatia		Switzerland		Morocco		Zambia
	Estonia		United Arab Emirates				

Note: The country classification here is based on regions except for in the "high-income" group, which includes rich countries from different regions

Table A2. Eigenvalues from PCA

Component	Eigenvalue	% of variance	Cumulative % of variance
Financial inclusion index			
1	2.84	56.20	56.87
2	0.92	18.50	75.37
3	0.69	14.30	89.25
4	0.33	7.00	95.92
5	0.20	4.00	100.00
ICT index			
1	2.18	72.80	72.80
2	0.58	19.65	92.46
3	0.22	7.53	100.00
Governance quality index			
1	4.93	82.26	82.26
2	0.43	7.31	89.57
3	0.38	6.38	95.95
4	0.13	2.25	98.21
5	0.06	1.08	99.29
6	0.04	0.70	100.00